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Title:

SEMICONDUCTOR MEMORY DEVICE

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## **SEMICONDUCTOR MEMORY DEVICE**

### **CROSS REFERENCES TO RELATED APPLICATIONS**

This application is a continuation of U.S. Patent Application No. 10/295,137, filed November 15, 2002, entitled "Semiconductor Memory Device," now U.S. Patent No. \_\_\_\_\_, which is hereby incorporated by reference in its entirety for all purposes.

### **BACKGROUND OF THE DISCLOSURE**

#### Field of the Disclosure:

The present disclosure relates generally to a semiconductor memory device. More particularly, the invention relates to a semiconductor memory device capable of reducing current consumed when a sensing operation is performed and thus can reduce power consumption.

#### Description of Related Art:

In order to select a single cell from a DRAM and to read data from the cell, a word line and a bit line pair are typically selected. Because the voltage differential in reading the data of the selected cell is low, however, the selected cell is usually sensed. Typically, all the cells coupled to a single word line are sensed due to refresh. Sensing a cell usually involves applying the potential of the power supply voltage to a restore node of a sense amplifier and applying the potential of the ground voltage to a sensing bar node. Due to

this, a large amount of current is typically required to sense the cells of a word line, and much power is consumed. Additionally, this may cause variations in the power supply voltage, leading to errors. Further, it is expected that the power consumption in a low power market using a battery will be an important problem.

After the sensing operation is performed, the word line, the restore node, the sensing bar node, and the bit line pair that were activated during the sensing operation are precharged to a bit line precharge voltage level before a next word line is activated. This may cause electric charges stored at the capacitor, which is charged with a HIGH or LOW level, to be unnecessarily discharged.

### **SUMMARY OF THE DISCLOSURE**

Some embodiments of the present invention may solve one or more (or none) of the above problems. Some embodiments of the present invention provide a semiconductor memory device capable of reducing current consumed when a sensing operation is performed and thus reduce power consumption.

In one embodiment, a semiconductor memory device is provided in which a potential of a restore node and a sensing bar node is raised to a given potential before a sensing operation is performed. After the sensing operation is performed, discharged electric charges may be stored and then used in a next sensing operation. Thus, the power consumption of the

semiconductor memory device may be reduced.

In one specific embodiment, a semiconductor memory device is provided. The memory device includes a memory cell array comprising a plurality of cells. The memory device also includes a plurality of sense amplifiers coupled to respective bit lines and respective bit-bar lines of respective cells in the plurality of cells, each of the plurality of sense amplifiers having a first terminal and a second terminal, and a control signal generating circuit to generate first, second, and third control signals. The memory device additionally includes a first switch to selectively couple the first terminals of the plurality of sense amplifiers to a power supply voltage terminal in response to the first control signal, and a second switch to selectively couple the second terminals of the plurality of sense amplifiers to a ground voltage terminal in response to the second control signal. The memory device further includes a third switch to selectively couple the first terminals of the plurality of sense amplifiers to a first charge recycling store in response to the third control signal, and a fourth switch to selectively couple the second terminals of the plurality of sense amplifiers to a second charge recycling store in response to the third control signal.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

The aforementioned aspects and other features of the present invention will be explained in the following description, taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a schematic diagram of one embodiment of a semiconductor memory device according to the present invention;

Fig. 2 is a schematic diagram of one embodiment of a control signal generating circuit according to the present invention;

Fig. 3 is a schematic diagram of one embodiment of a charge recycling circuit according to the present invention; and

Fig. 4 is a timing diagram for describing one embodiment of a method of driving the semiconductor memory device according to the present invention.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention will be described in detail by way of a preferred embodiment with reference to accompanying drawings, in which like reference numerals are used to identify the same or similar parts.

Fig. 1 is a schematic diagram of one embodiment of a semiconductor memory device according to the present invention.

Referring now to Fig. 1, the semiconductor memory device includes a plurality of memory cell arrays **11 - 1n**, and a plurality of bit line sense amplifiers **21 - 2n, 31 - 3n** formed depending on a bit line **bit** and a bit-bar line **bitb**, which are formed on an upper portion and lower portion of the memory cell array **11 - 1n**. The sense amplifiers **21 - 2n, 31 - 3n** are coupled to a restore node **rto** and a sensing bar node **sb**. PMOS transistors **P11** and **P12** driven by a first control signal **rtoex** are coupled between the power supply

terminal (**Vcc**) and the restore node **rto**. NMOS transistors **N11** and **N12** driven by a second control signal **sxez** are coupled between the sensing bar node **sb** and the ground terminal (**Vss**). Meanwhile, a first capacitor **Crto** is coupled between the restore node **rto** and the ground terminal (**Vss**). A second capacitor **Csb** is coupled between the sensing bar node **sb** and the ground terminal. First and second charge recycling circuits **41** and **42** are driven by a power-up signal **pwrap** and a third control signal **xfer** to supply the restore node **rto** and the sensing bar node **sb** with the potentials of the sense amplifiers **21 - 2n, 31 - 3n**. Control signal generating circuits **51** and **52** are driven by a bit line precharge signal **blpz**, a bit line sense amplifier enable signal **sgz** and a word line enable address signal **pxz** to generate the first and second control signals **rtoex** and **sxez** and the third control signal **xfer** for driving the first and second charge recycling circuits **41** and **42**.

A method of driving the semiconductor memory device constructed above according to the present invention will be explained below.

If the word line is activated in a state that the plurality of the bit line sense amplifiers **21 - 2n, 31 - 3n** are coupled by the bit line **bit** and the bit-bar line **bitb** on the upper and lower portions of the plurality of the memory cell arrays **11 - 1n**, a small voltage differential is generated by distribution of electric charges of the capacitance of a cell coupled to the bit line and the capacitance of the bit line itself. In order to increase this voltage differential, the first control signal **rtoex** is applied with a LOW state and the second control signal **sxez** is applied with a HIGH state, so that the PMOS transistors

P11 and P12 and the NMOS transistors N11 and N12 are simultaneously turned on. Thereby, the restore node **rto** keeps the potential of the power supply voltage (**Vcc**) and the sensing bar node **sb** keeps the potential of the ground voltage (**Vss**). If the third control signal **xfer** is then applied with a HIGH state, the charge recycling circuits **41** and **42**, driven by the third control signal **xfer**, supply a given potential to the restore node **rto** and the sensing bar node **sb**. It is therefore possible to shorten the time to raise the potential of the restore node **rto** and the sensing bar node **sb** to a predetermined voltage or lower the potential of the restore node **rto** and the sensing bar node **sb** down to a predetermined voltage.

After the sensing operation of the sense amplifiers **21 - 2n**, **31 - 3n** is sufficiently performed, the word line, the restore node **rto**, the sensing bar node **sb**, the bit line **bit**, and the bit-bar line **bitb** are precharged with the bit line precharge voltage level before a next word line is activated. Also, the stored electric charges are discharged to a capacitor, which will thus be charged with a HIGH level or LOW level. At this time, as the electric charges of a given amount are transferred to the charge recycling circuits **41** and **42** before the capacitor starts to discharge, the voltage that was varied by distribution of the voltage is restored to its original state.

Referring now to Fig. 2, a structure of one embodiment of the control signal generating circuit according to the present invention will be below described.

A first PMOS transistor **P101** driven by the bit line sense amplifier

enable signal **sgz** is coupled between the power supply terminal (**Vcc**) and a first node **Q101**. A first NMOS transistor **N101** driven by the bit line sense amplifier enable signal **sgz** and a second NMOS transistor **N102** driven by a signal of a bit line precharge signal **blpz** that is inverted by a first inverter **I101**, are serially coupled between the first node **Q101** and the ground terminal **Vss**. The potential of the first node **Q101** is latched in a first latch means **101** having second and third inverters **I102** and **I103**. An output signal of the first latch means **101** is inverted and delayed through fourth - sixth inverters **I104** - **I106** to drive a third PMOS transistor **P103** coupled to an output terminal of the second control signal **sxez** and a third NMOS transistor **N103** coupled between the output terminal of the second control signal **sxez** and the ground terminal (**Vss**). Meanwhile, the second PMOS transistor **P102** for always maintaining a turn-on state, having a gate terminal coupled to the ground voltage (**Vss**), and a first resistor **R101** are coupled between the power supply terminal (**Vcc**) and the output terminal of the second control signal **sxez**.

Also, the output signal of the first latch means **101** is delayed through seventh - tenth inverters **I107** - **I110** to drive a fourth PMOS transistor **P104** coupled between the power supply **Vcc** and the output terminal of the first control signal **rtoex** and a fourth NMOS transistor **N104** coupled to the output terminal of the first control signal **rtoex**. Meanwhile, the fourth NMOS transistor **N104**, a second resistor **R102**, and a fifth NMOS transistor **N105** for always maintaining a turn-on state, having a gate terminal coupled to the power supply voltage (**Vcc**), are serially coupled between the output terminal

of the first control signal **rtoex** and the ground terminal (**Vss**).

A fifth PMOS transistor **P105** driven by the bit line sense amplifier enable signal **sgz** is coupled between the power supply terminal (**Vcc**) and the fifth node **Q105**. A sixth NMOS transistor **N106** driven by the bit line sense amplifier enable signal **sgz** and a seventh NMOS transistor **N107** driven by an output signal of a first NOR gate **102** for logically combining word line enable address signals **pxz<0:3>** are coupled between the fifth node **Q105** and the ground terminal (**Vss**). The potential of the fifth node **Q105** is inverted by the eleventh inverter **I111** and is then applied to one input terminal of a third NOR gate **104**.

A reference numeral **106** indicates a post precharge circuit that outputs a pulse of a fixed width. The second NOR gate **103** logically combines the potential of the second node **Q102** and the output signal of the seventh inverter **I107**. An output signal of the second NOR gate **103** is inverted and delayed by twelfth - fourteenth inverters **I112 - I114** to drive the sixth PMOS transistor **P106** coupled between the power supply terminal (**Vcc**) and the sixth node **Q106**. An output signal of the second NOR gate **103** is also delayed by the twelfth - fifteenth inverters **I112 - I115** and is then inputted to the other input terminal of the third NOR gate **104**. The potential of the sixth node **Q106** is inverted and delayed by sixteenth - eighteenth inverters **I116 - I118** and is then latched in the second latch means **105** to become the potential of the second node **Q102**. Meanwhile, the eighth NMOS transistor **N108** coupled between the sixth node **Q106** and the ground terminal (**Vss**) is driven by the power-up

signal **pwrap**. Also, the sixth PMOS transistor **P106** coupled between the power supply terminal (**Vcc**) and the sixth node **Q106** is driven by an output signal of the fourteenth inverter **I114**.

The output signal of the third NOR gate **104** is inverted through the twenty- first inverter **I121** and is then outputted as the third control signal **xfer**.

One embodiment of a method of driving the control signal generating circuit constructed above according to the present invention will be described by reference to the timing diagram of Fig. 4.

The bit line sense amplifier enable signal **sgz** is a signal that could not drive the selected block only since it is a bank global. Therefore, the first and second control signals **rtoex** and **sxez** for supplying the power supply to the restore node **rto** and the sensing bar node **sb** are generated using the bit line precharge signal **blpz** that is driven only at the selected block. If the bit line precharge signal **blpz** is at a LOW state, the bit line precharge signal **blpz** is inverted to a HIGH state through the first inverter **I101**, thus turning on the second NMOS transistor **N102**. Also, the first word line enable address signal **pxz<0>** may be applied with a HIGH state to enable the word line thereof. The first NOR gate **102** logically combines the first word line enable address signal **pxz<0>** to output a signal of a LOW state. The seventh NMOS transistor **N107** is turned off by the output signal of the first NOR gate **102** that is outputted with a LOW state. In this state, the bit line sense amplifier enable signal **sgz** is applied with a HIGH state to turn off the first and fifth PMOS transistors **P101** and **P105** and also to turn on the first and

sixth NMOS transistors **N101** and **N106**. Thereafter, the first node **Q101** keeps a LOW state and the fifth node **Q105** keeps a HIGH state. The potential of the first node **Q101** that is maintained as the LOW state is latched in the first latch means **101**. As a result, the first latch means **101** outputs a signal of a HIGH state. The output signal of the first latch means **101** that is maintained as the HIGH state is inverted to a LOW state and delayed through the fourth - sixth inverters **I104 - I106**, so that the third PMOS transistor **P103** is turned on and the third NMOS transistor **N103** is turned off. Therefore, as the power supply voltage (**Vcc**) is supplied through the first resistor **R101** and the second and third PMOS transistors **P102** and **P103**, the second control signal **sxez** of a HIGH state is outputted.

The output signal of the first latch means **101** that is maintained as the HIGH state is delayed through the seventh - tenth inverters **I107 - I110** to turn off the fourth PMOS transistor **P104** and to turn on the fourth NMOS transistor **N104**. Therefore, a current path is formed between the output terminal of the first control signal **rtoex** and the ground terminal (**Vss**) through the fourth NMOS transistor **N104**, the second resistor **R102** and the fifth NMOS transistor **N105**, so that the first control signal **rtoex** of a LOW state is outputted.

As the eighth NMOS transistor **N108** is turned on by the power-up signal **pwrup**, the sixth node **Q106** keeps a LOW state. The potential of the sixth node **Q106** that is maintained as the LOW state is inverted to a HIGH state and delayed through the sixteenth - eighteenth inverters **I116 - I118**.

The second latch means **105** latches the potential of the sixth node **Q106** to output a signal of a LOW state. Thus, the second node **Q102** maintains a potential of a LOW state. The second NOR gate **103** logically combines the output signal of the seventh inverter **I107** that is outputted with a LOW state, and the potential of the second node **Q102** that is maintained as the LOW state to output a signal of a HIGH state. Also, the output signal of the second NOR gate **103** that is maintained as the HIGH state is delayed through the twelfth - fifteenth inverters **I112 - I115** and is then inputted with a HIGH state to the third NOR gate **104**. The third NOR gate **104** logically combines the output signal of the fifteenth inverter **I115** that is maintained as the HIGH state and the potential of the fourth node **Q104** that is maintained as the LOW state in which the potential of the fifth node **Q105** that is maintained as the HIGH state are inverted through the eleventh inverter **I111**, to thus output a signal of a LOW state. The output signal of the third NOR gate **104** that is maintained as the LOW state is inverted to a HIGH state through the twenty-first inverter **I121** and is then outputted as the third control signal **xfer**.

Meanwhile, the output signal of the second NOR gate **103** that is outputted as a HIGH state is inverted to a LOW state through the twelfth - fourteenth inverters **I112 - I114** to turn on the sixth PMOS transistor **P106**. At this time, as the power-up signal **pwrap** is a state that is shifted to a LOW state, the eighth NMOS transistor **N108** is turned off. Therefore, the sixth node **Q106** keeps a HIGH state. The potential of the sixth node **Q106** that is maintained as the HIGH state is inverted to a LOW state and delayed through

the sixteenth - eighteenth inverters **I116 - I118**. The second latch means **105** latches the potential of the sixth node **Q106** to output a signal of a HIGH state, so that the second node **103** maintains a potential of the HIGH state. The second NOR gate **103** logically combines the output signal of the seventh inverter **I107** that is outputted as a LOW state and the potential of the second node **103** that is maintained as the HIGH state to output a signal of a LOW state. The output signal of the second NOR gate **103** that is maintained as the LOW state is delayed through the twelfth - fifteenth inverters **I112 - I115** and is then inputted with a LOW state to the third NOR gate **104**. The third NOR gate **104** logically combines the output signal of the fifteenth inverter **I115** that is maintained as the LOW state and the potential of the fourth node **Q104** that is maintained as the LOW state to output a signal of a HIGH state. The output signal of the third NOR gate **104** that is maintained as the HIGH state is inverted to a LOW state through the twenty-first inverter **I121** and is then outputted as the third control signal **xfer**.

If all the word line enable address signals **pxz<0:3>** are shifted to a LOW state to disable the word line, the first NOR gate **102** logically combines all the word line enable address signals **pxz<0:3>** to output a signal of a HIGH state. Then, the fifth node **Q105** shifts the potential of the HIGH state to a potential of a LOW state when the seventh NMOS transistor **N107** is turned on. This potential of the LOW state is inverted to a HIGH state through the eleventh inverter **I111**, so that it becomes the potential of the fourth node **Q104**. Next, the third NOR gate **104** logically combines the potential of the

fourth node **Q104** that is maintained as the HIGH state and the output signal of the fifteenth inverter **I115** that is maintained as the HIGH state to output a signal of a LOW state. Also, the output signal of the third NOR gate **104** that is maintained as the LOW state is inverted to a HIGH state through the twenty-first inverter **I121** and is then outputted as the third control signal **xfer**.

The bit line sense amplifier enable signal **sgz** is applied with a LOW state to turn on the first and fifth PMOS transistors **P101** and **P105** and to turn off the first and sixth NMOS transistors **N101** and **N106**. Therefore, the first node **Q101** keeps a HIGH state and the fifth node **Q105** also keeps the HIGH state. At this time, the first latch means **101** latches the potential of the first node **Q101** that is maintained as the HIGH state to output the first latch means **101** of a LOW state. Also, the output signal of the first latch means **101** that is maintained as the LOW state is inverted to a HIGH state and delayed through the fourth - sixth inverters **I104** - **I106** to turn off the third PMOS transistor **P103** and to turn on the third NMOS transistor **N103**. Therefore, the second control signal **sxez** of a LOW state is outputted. Further, the output signal of the first latch means **101** that is maintained as the LOW state is delayed through the seventh - tenth inverters **I107** - **I110** to turn on the fourth PMOS transistor **P104** and to turn off the fourth NMOS transistor **N104**. The first control signal **rtoex** of a HIGH state is thus outputted.

The potential of the sixth node **Q106** that is maintained as the HIGH state is inverted to a LOW state and delayed through the sixteenth - eighteenth inverters **I116** - **I118**. The second latch means **105** then latches the potential

of the sixth node **Q106** to output a signal of a HIGH state, so that the second node **Q102** keeps a potential of a HIGH state. The second NOR gate **103** logically combines the output signal of the seventh inverter **I107** that is outputted as a HIGH state and the potential of the second node **Q102** that is maintained as the LOW state to output a signal of a LOW state. The output signal of the second NOR gate **103** that is maintained as the LOW state is delayed through the twelfth - fifteenth inverters **I112 - I115** and is then inputted with a LOW state to the third NOR gate **104**. Then, the third NOR gate **104** logically combines the output signal of the fifteenth inverter **I115** that is maintained as the LOW state and the potential of the fourth node **Q104** that is maintained as the LOW state to output a signal of a HIGH state. Next, the output signal of the third NOR gate **104** that is maintained as the HIGH state is inverted to a LOW state through the twenty-first inverter **I121** and is then outputted as the third control signal **xfer**.

As described, if the bit line precharge signal **blpz** is applied with a LOW state, the bit line sense amplifier enable signal **sgz** is applied with a HIGH state and one of the word line enable address signals **pxz<0:3>** is applied with a HIGH state in the control signal generating circuit, the first control signal **rtoex** is outputted as a HIGH state, the second control signal **sxez** is outputted as a LOW state and the third control signal **xfer** is outputted as a HIGH state for a determined time period.

Also, if the word line enable signals **pxz<0:3>** are shifted to a LOW state to disable the word line in a state that the bit line precharge signal **blpz** is

applied with a LOW state and the bit line sense amplifier enable signal **sgz** is applied with a HIGH state, the third control signal **xfer** is outputted as a HIGH state. Next, if the bit line sense amplifier enable signal **sgz** is shifted to a LOW state, the first control signal **rtoex** is outputted as a HIGH state, the second control signal **sxez** is outputted as a LOW state and the third control signal **xfer** is outputted as a LOW state.

Referring now to Fig. 3, a structure of one embodiment of the charge recycling circuit according to the present invention will be below described.

A first PMOS transistor **P201** coupled between the power supply terminal (**Vcc**) and a first node **Q201** is driven by a signal of a power-up signal **pwrup** that is inverted by the first inverter **I201**. A first capacitor **C201** is coupled to the first node **Q201**. Also, a first transfer gate **T201** that is driven by the third control signal **xfer** and an output signal of a second inverter **I202** for inverting the third control signal **xfer** is coupled between the first node **Q201** and the restore node **rto**. A first NMOS transistor **N201** driven by the power-up signal **pwrup** is coupled between a second node **Q202** and the ground terminal (**Vss**). A second capacitor **C202** is coupled to the second node **Q202**. Also, the second transfer gate **T202** that is driven by the third control signal **xfer** and an output signal of the second inverter **I202** for inverting the third control signal **xfer** is coupled between the second node **Q202** and the sensing bar node **sb**.

A method of driving the charge recycling circuit constructed above according to the present invention will be below described by reference to the

timing diagram of Fig. 4.

If the power-up signal **pwrap** is applied with a HIGH state, the power-up signal **pwrap** is inverted to a LOW state through the first inverter **I201**.

Thereby, the first PMOS transistor **P201** is turned on by the signal of the LOW state. The power supply voltage (**Vcc**) is thus supplied to the first node **Q201**.

Therefore, the first node **Q201** keeps the potential of the power supply voltage (**Vcc**) and the first capacitor **C201** is charged with electric charges.

Meanwhile, the first NMOS transistor **N201** is turned on by the power-up signal **pwrap** applied with a HIGH state and the second node **Q202** keeps the potential of the ground voltage (**Vss**). At this time, the electric charges

charged at the second capacitor **C202** are discharged to the ground terminal

(**Vss**). At this state, if the power-up signal **pwrap** is inverted to a LOW state

and the third control signal **xfer** is applied with a HIGH state, the first and second transfer gates **T201** and **T202** are turned on by the third control signal **xfer** of a HIGH state and a signal of a LOW state being a signal of the third control signal **xfer** inverted by the second inverter **I202**. Therefore, the

potential of the first node **Q201** is transferred to the restore node **rto** and the potential of the second node **Q202** is also transferred to the sensing bar node **sb**. Thus, the potential of the first node **Q201** has a potential (**Vcc-dV**)

dropped by a voltage that is distributed by the cell capacitance and the capacitance of the bit line itself. Also, the potential of the second node **Q202** has a potential (**dV**) that is raised by that amount.

If the third control signal **xfer** is shifted to a LOW state, the first and

second transfer gates **T201** and **T202** are turned off, so that connection between the first node **Q201** and the restore node **rto**, and between the second node **Q202** and the sensing bar node **sb** is decoupled.

If the word line enable address signal **pxz<0>** is shifted to a LOW state to disable the word line after the sensing operation is performed, the third control signal **xfer** is applied with a HIGH state. Thereby, the first and second transfer gates **T201** and **T202** are turned on, so that the restore node **rto** and the first node **Q201** are coupled, and the sensing bar node **sb** and the second node **Q202** are also coupled. Therefore, the first node **Q201** keeps the potential of the power supply voltage (**Vcc**) and the second node **Q202** keeps the potential of the ground voltage (**Vss**). Also, if the bit line sense amplifier enable signal **sgz** is shifted to a LOW state, the first and second transfer gates **T201** and **T202** are turned off since the third control signal **xfer** is shifted to a LOW state. Therefore, connection between the restore node **rto** and the first node **Q201** and between the sensing bar node **sb** and the second node **Q202** is decoupled. Further, the first node **Q201** keeps the potential of the power supply voltage (**Vcc**) and the second node **Q202** keeps the potential of the ground voltage (**Vss**).

In the embodiment described above, a charge recycling circuit is driven to raise a potential of a restore node and a sensing bar node to a given potential before a sensing operation is performed. After the sensing operation is performed, electric charges discharged from the restore node and the sensing bar node are stored using the charge recycling circuit, and may then be used

when a next sensing operation is performed. Therefore, current consumption when the sensing operation is performed can be reduced and can thus reduce the power consumption.

An embodiment of the present invention has been described with reference to a particular embodiment in connection with a particular application. Those having ordinary skill in the art and access to the teachings of the present invention will recognize additional modifications and applications within the scope thereof.

It is therefore intended by the appended claims to cover any and all such applications, modifications, and embodiments within the scope of the present invention.